

**UNITED STATES PATENT APPLICATION**

*of*

**DARIO GIL,**

**RAJESH MENON,**

**DAVID CARTER,**

**HENRY I. SMITH**

*and*

**GEORGE BARBASTATHIS**

*For a*

**SYSTEM AND METHOD FOR MASKLESS LITHOGRAPHY USING  
AN ARRAY OF SOURCES AND AN ARRAY OF  
FOCUSING ELEMENTS**

## **PRIORITY**

This application claims priority to U.S. Provisional Application Ser. No. 60/400,812 filed August 2, 2002. This invention was made with support from the United States government under Grant No. DAAD19-01-1-0330, and the United States government has certain rights to the invention.

## **BACKGROUND OF THE INVENTION**

The invention relates to maskless lithography, and relates in particular to maskless lithography using arrays of focusing elements.

U.S. Patent No. 5,900,637 discloses a system for maskless lithography that involves the focusing of incident energy from a single energy source onto a substrate as focused beamlets. The arrangement includes micro-mechanical devices with actuatable shutters that turn the focused beams on and off in response to commands from a control computer. To write a pattern, the substrate is scanned under the array, while the individual beams are turned on and off as needed by means of the micro-mechanical shutters, one associated with each zone plate. These shutters are disclosed to be located either between the zone plate array and the substrate, or between the zone plate array and the source of radiation. The '637 patent also discloses a lithography system that includes an array of micro-mechanical, deflectable glancing-angle mirrors that may be used to turn individual focused beams on and off.

Such lithography systems, however, require that micro-mechanical shutters or mirrors be very precise and accurately turned on and off repeatedly without significant variation. In certain

applications the use of micro-mechanical shutters or mirrors may not be appropriate.

There remains a need therefore, for a maskless lithography system that does not rely on micro-mechanical devices to write using individual zone plates or other diffractive elements.

## **SUMMARY OF THE INVENTION**

The invention provides a maskless lithography system in accordance with an embodiment that includes an array of focusing elements, each of which focuses an energy beam from an array of sources into an array of focal spots in order to create a permanent pattern on an adjacent substrate.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

The following description may be further understood with reference to the accompanying drawings in which:

Figure 1 shows an illustrative diagrammatic exploded view of an array of energy sources and an array of diffractive elements for use in a system in accordance with an embodiment of the invention; and

Figure 2 shows an illustrative diagrammatic sectional view of a system in accordance with an embodiment of the invention.

The drawings are shown for illustrative purposes and are not to scale.

## **DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS**

The lithography systems in accordance with the invention may be used with arrays of a variety of focusing elements, such as Fresnel zone plates as disclosed in U.S. Patent No. 5,900,637,

the disclosure of which is hereby incorporated by reference. As shown in Figure 1, an array of focusing elements 10 may be arranged on a silicon substrate 12, wherein each zone plate defines a unit cell. The array is supported on a thin membrane with vertical, anisotropically-etched silicon (Si) joists 14 for rigid mechanical support that divide rows of unit cells. Each zone plate is responsible for exposure only within its unit cell. The silicon joists are intended to provide additional rigidity to the array while minimizing obstruction. Methods of anisotropic etching of silicon are well known, and are capable of producing in silicon joists of about one or a few micrometers in thickness. In alternative embodiments of the invention, the joists may not be necessary, and the substrate need not be formed of silicon. The membrane is formed of a material that is transparent to the beam source. If the source is 4.5nm x-ray, then the membrane may be formed of a thin carbonaceous material. If deep UV radiation is used, the membrane may be made of glass, and the zone plates may be made from phase zone plates, e.g., grooves cut into a glass plate or membrane.

An array of individually selectable sources 16 is also provided on a support substrate 18 such that each source is aligned with one of the focusing elements 10. The sources may be semiconductor lasers, diode lasers, light emitting diodes (LEDs), vertical cavity surface emitting lasers (VCSELs) or a variety of other sources such as x-ray sources or electron beam sources. These may be microfabricated in arrays, and may provide extremely high modulation frequencies (about 1 GHz), which translates to very high patterning speeds.

The focusing elements may be any of a variety of diffractive and/or refractive elements including those disclosed in U.S. Patent Application Ser. No. 10/---,--- filed July 22, 2003, (the disclosure of which is hereby incorporated by reference) which claims priority to U.S. Provisional

Applications Ser. Nos. 60/397,705 and 60/404,514, including, for example, amplitude and/or phase Fresnel zone plates, blazed Fresnel zone plates, Bessel zone plates, photon sieves (e.g., amplitude photon sieves, phase photon sieves, or alternating phase photon sieves), and the diffractive focusing elements may be apodized. These may be microfabricated in large arrays as well, and may be designed to compensate for wavefront characteristics in the radiation output from the source array to achieve, for example, the smallest possible focal spot.

Figure 2 shows a cross-sectional schematic view of an embodiment of a maskless lithography arrangement in accordance with the invention illustrating the focusing of incident beams 22 from the array of beam sources 16 onto a substrate 24 that is coated with a resist 26 as focused beams 28. The incident beams 22 are individually turned on and off in response to commands from a control computer 30. Shutter devices may further be interposed on either side of the array of diffractive elements 10 in certain embodiments.

Each of diffractive elements 10 on the membrane 12 is able to focus an individual beam 22 to a fine focal spot 32 on the resist-coated substrate 24, which is supported on a positioning stage. To write a pattern, the substrate is scanned under the array, while the individual beams 28 are turned on and off as needed by means of the individual energy sources 16, wherein one energy source is associated with one zone plate as shown in Figure 1.

There are various strategies through which the scanning and writing may be achieved. For example, a serpentine writing scheme may be employed, with the substrate scanned in X and Y by a fast piezoelectric system (not shown), thereby filling in the full pattern. A square array of zone plates, with each zone plate writing only within its unit cell as discussed above is provided. The scanning in this case could be serpentine, with the positioning stage moving only a distance equal to

the unit cell edge dimension in X and Y until all pixels within the unit cell are addressed, and either written (e.g., individual illumination sources are on) at a focal spot or not (i.e., individual illumination source off). The entire array would then be stepped a distance equal to the array size and scanning repeated. An alternative to a this step-and-scan strategy, is a linear-scan strategy similar to that described by M. Feldman, OSA Proceedings on Soft-X-ray Projection Lithography, Eds. A. M. Hawryluk and R. H. Stulen (Opt. Soc. Amer., Washington, D.C.) 18, 207 (1993), incorporated herein by reference. In Feldman's scheme, a close-packed array of zone plates would be azimuthally rotated relative to the scanning direction in such a way that all pixels may be addressed when the substrate is scanned along one direction only.

By selectively modulating the each of an array of energy (or light) sources, while scanning a substrate, one may create arbitrary patterns. Such a system may be extremely compact (integrated) and have very high resolution and throughput.

The arrays of sources and of focusing elements may be two or three dimensional. The array of sources direct radiation onto the array of diffractive focusing elements. In certain embodiments, the array of sources may have an array of diffractive or refractive lenses to collimate the radiation, and in certain embodiments, the each of the lenses may be coupled directly to and thereby included with each of the sources 16 in Figure 1. There would be a one to one correspondence between each light source, each lens and each diffractive focusing element. The radiation incident on each diffractive focusing element is focused into an individual spot. Because the substrate 24 that is coated with radiation-sensitive chemical 26 (such as photoresist) is placed in the focal plane of the diffractive focusing element, the pattern of spots may be transferred onto the substrate. By scanning the susbstrate therefore, one may make arbitrary patterns. The sources and focusing-lens arrays may

be microfabricated on separate substrates. These substrates may be aligned and bonded together, thereby creating a very compact, maskless lithography print-head.

The invention also provides a method for performing maskless patterning using an array of light sources (which again, may be diode lasers, LEDs, VCSELs etc.) and an array of focusing lenses (which again may diffractive or refractive or any combination thereof). The natural parallelism of such a multi-optical column writing technique when combined with the high modulation frequencies of light sources may result in a high resolution and high throughput patterning system. The proposed method consists of the following steps: a) providing an array of sources including but not limited to VCSELs, LEDs, laser diodes, sources of any wavelength, x-ray sources and even electron beam sources; b) providing an array of collimating microlenses or diffractive lenses to collimate and clean-up the source array output beam; c) providing an array of focusing lenses that may be zone plates, photon sieves, bessel zone plates, other diffractive lenses, refractive lenses, combinations of diffractive and refractive lenses, or any other elements that may be used to focus the incident radiation into an array of spots; d) individually switching the sources on and off; and e) scanning a substrate on a stage underneath the focused beams to create a pattern. Note that, the modulation of such sources may be extremely fast. Moreover, such sources may grayscale their intensity for more accurate patterning and correct for light non-uniformity across the source array. To improve the resolution of the pattern, one may even use the system in an immersion fluid.

Those skilled in the art will appreciate that numerous modifications and variations may be made to the above disclosed embodiments without departing from the spirit and scope of the invention.

What is claimed is: